2. PHYSICAL AND CHEMICAL OCEANOGRAPHY

To address Factor 2 (biological, physical, and chemical transport processes) of the 10 factors used to determine unreasonable degradation, the physical and chemical oceanography of the eastern Gulf of Mexico, or the receiving waters, are characterized.

2.1 Physical Oceanography

Physical oceanography is the marine science that describes the motions of ocean waters (e.g., currents, tides, and waves) as well as the physical properties of seawater such as temperature and salinity (Kennish, 1989). The physical oceanographic conditions of the receiving waters will influence the fate of discharges and the eventual exposure of marine organisms to those discharges.

2.1.1 Circulation

Circulation patterns in the Gulf of Mexico are characterized by two interrelated systems, the offshore or open Gulf, and the shelf or inshore Gulf. Both systems involve the dynamic interaction of a variety of factors. Open Gulf circulation is influenced by eddies, gyres, winds, waves, freshwater input, density of the water column, and currents. Offshore water masses in the eastern Gulf may be partitioned into a Loop Current, a Florida Estuarine Gyre in the northeastern Gulf, and a Florida Bay Gyre in the southeastern Gulf (Austin, 1970).

The strongest influence on circulation in the eastern Gulf of Mexico is the Loop Current (Figure 1) (MMS, 2000a). The location of the Loop Current is variable, with fluctuations that range over the outer shelf, the slopes, and the abyssal areas off Mississippi, Alabama, and Florida (Figure 2). Within this zone, short-term strong currents exist, but no permanent currents have been identified (MMS, 1990). The Loop Current forms as the Yucatan Current enters the Gulf through the Yucatan Straits and travels through the eastern and central Gulf before exiting via the Straits of Florida and merging with other water masses to become the Gulf Stream (Leipper, 1970; Maul, 1977). The Loop Current extends to about 1000 m depth with surface speeds as high as 150-200 cm/s, decreasing with depth (MMS 2000a).

In the shelf or inshore Gulf region, circulation within the Mississippi, Alabama, and west Florida shelf areas is controlled by the Loop Current, winds, topography, and tides. Freshwater input also acts as a major influence in the Mississippi/Alabama shelf and eddy-like perturbations play a significant role in the west Florida shelf circulation. Current velocities along the shelf are variable. Brooks (1991) found that average current velocities in the Mississippi/Alabama shelf area were are about 1.5 centimeters per second and east-west and northeast-southwest directions dominate. MMS (1990) data showed that winter surface circulation is directed along shore and westward with flow averaging 4 cm/s to 7 cm/s (Figure 3). During the spring and summer, the current shifts to the east with flow averaging 2 cm/s to 7 cm/s (Figure 4). The mean circulation on the west Florida shelf is directed southward with mean flow ranging from 0.2 cm/s to 7 cm/s (MMS, 1990).

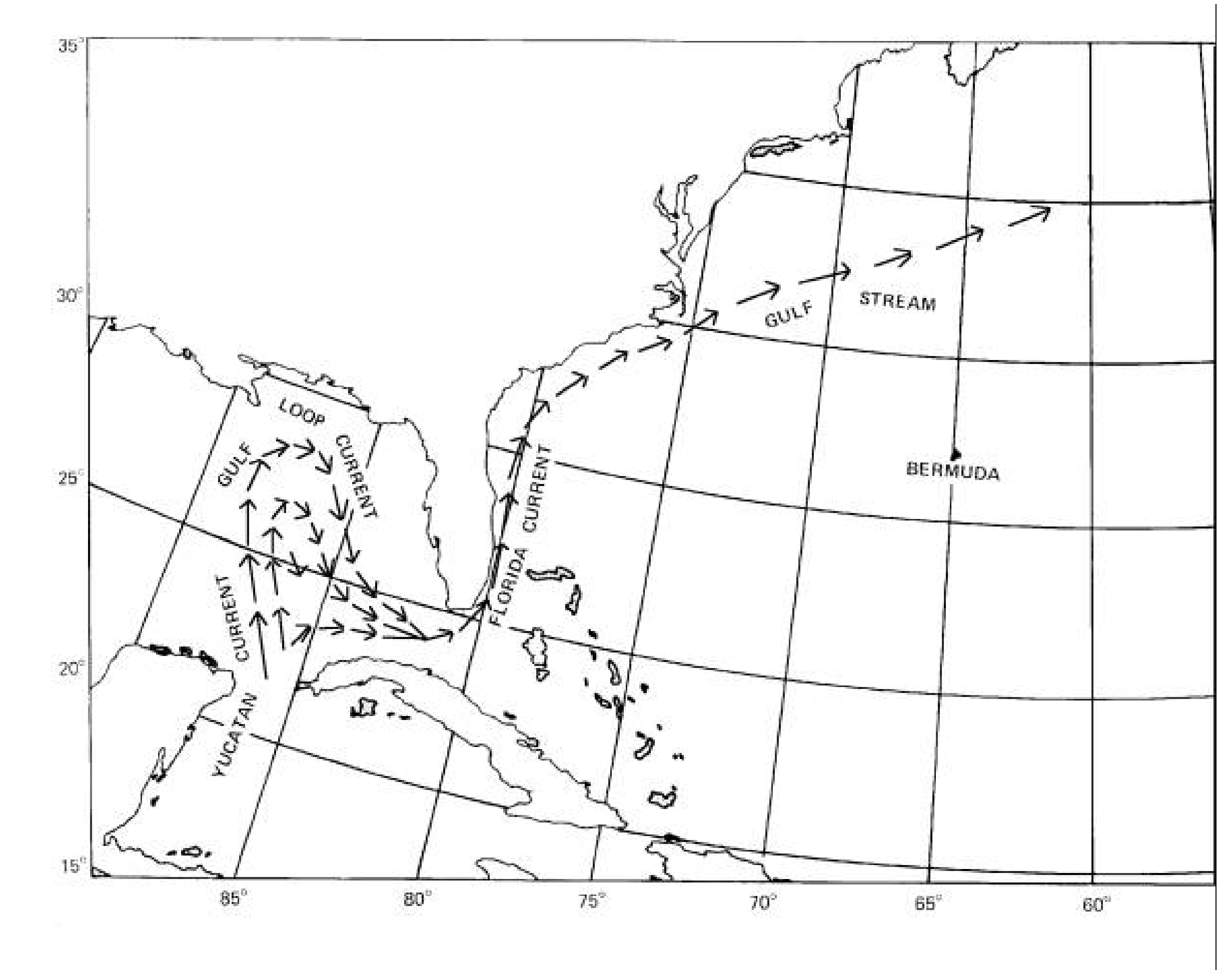


Figure 2-1. The Loop Current in the Gulf of Mexico.

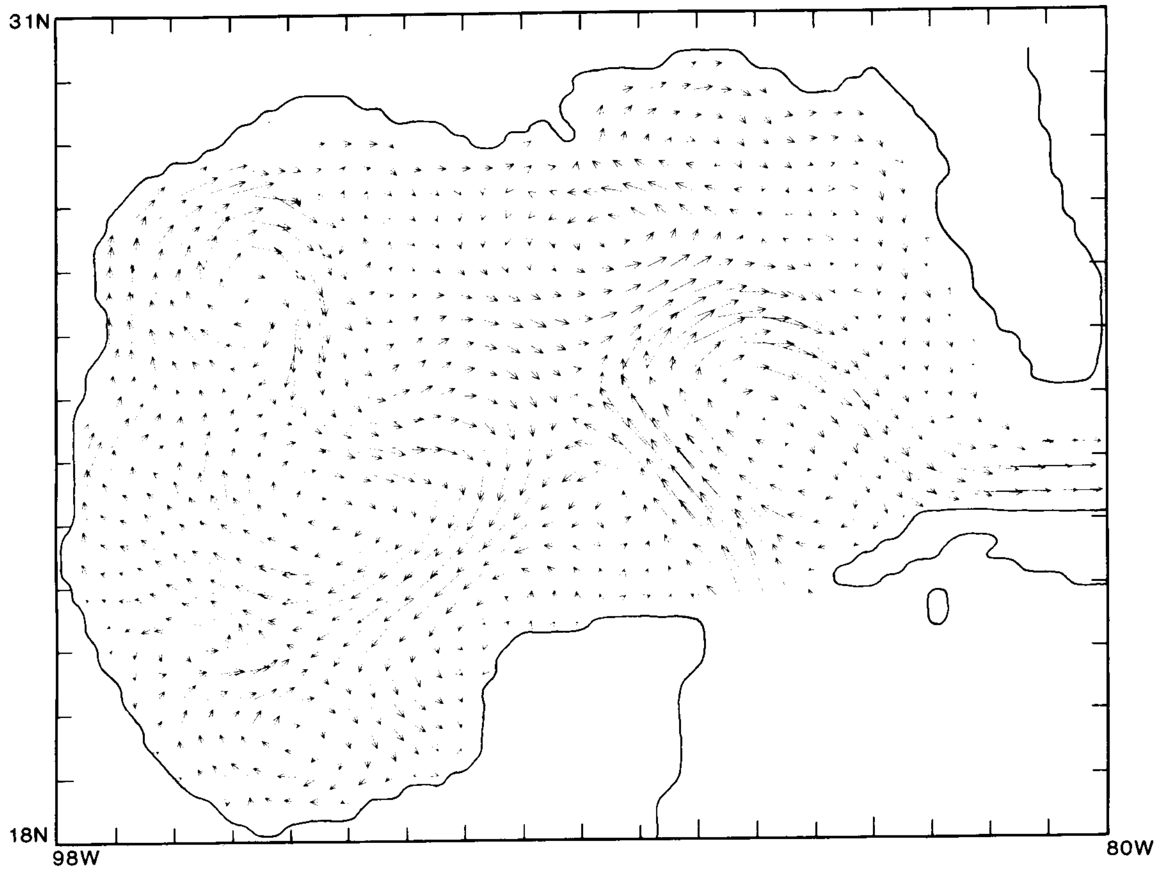


Figure 2-2. Model simulation of Gulf of Mexico currents. (Modified from Wallcraft, 1985).

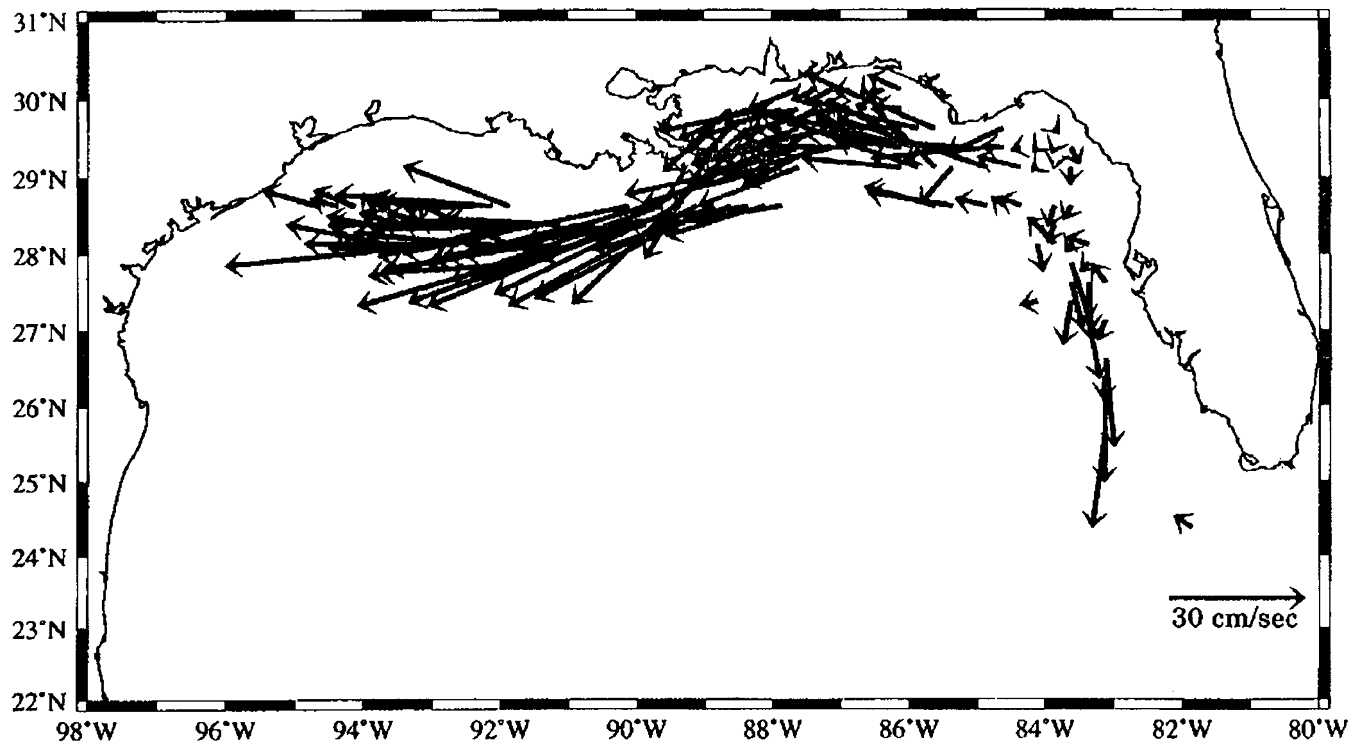


Figure 2-3. Average shelf surface current vectors for drifter buoys deployed from October 1996 and 1997. (Modified from DOI, 2000).

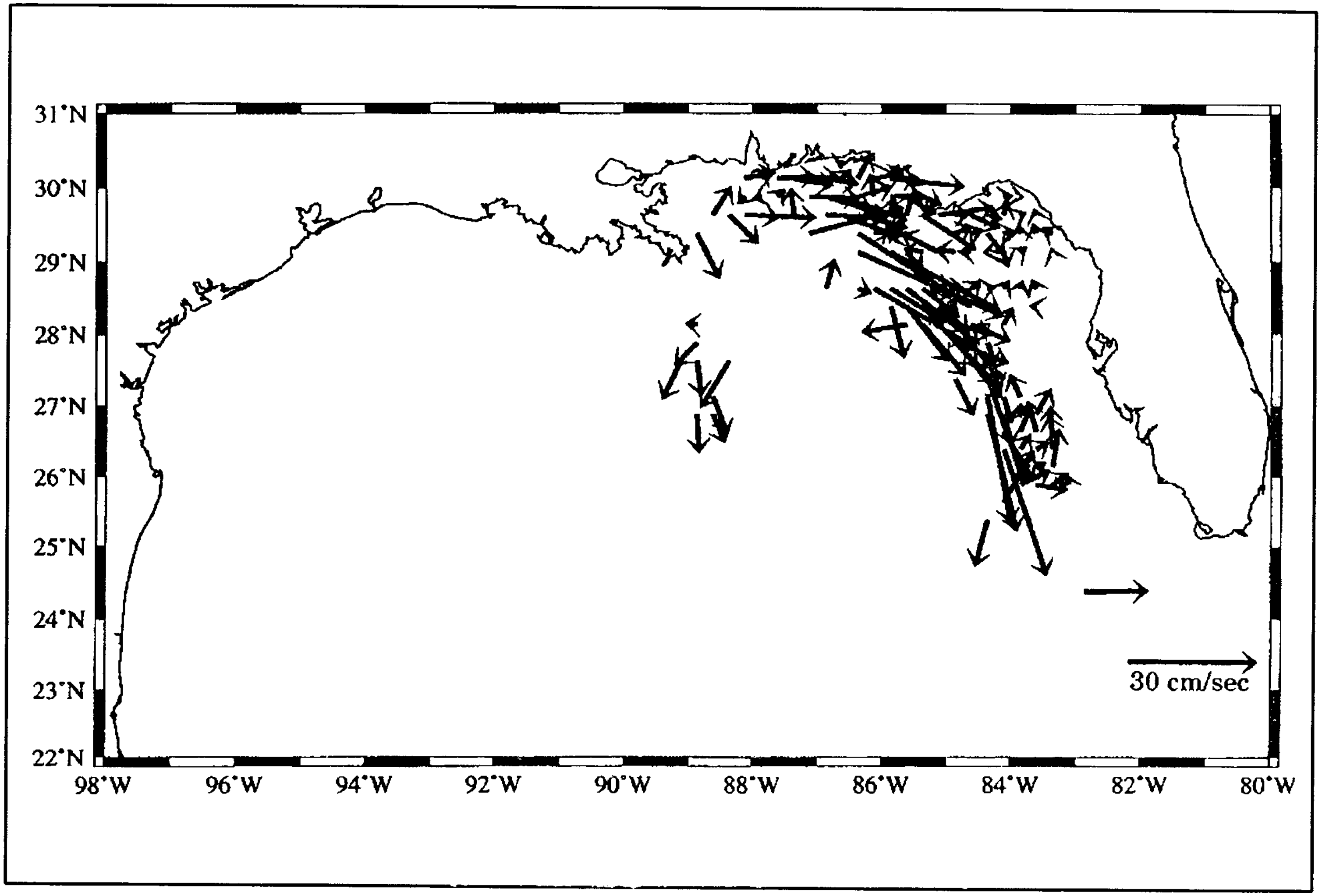


Figure 2-4. Average shelf surface current vectors for drifter buoys deployed from July 1996 and 1997. (Modified from DOI, 2000).

Wind patterns in the Gulf are primarily anticyclonic (clockwise around high pressure areas), and tend to follow an annual cycle; winter winds from the north and southeast and summer winds from the northeast and south (Figure 5). During the winter, mean wind speeds range from 8 knots to 18 knots. Several examples of mean annual wind speeds in the eastern Gulf are 8.0 millibars (mb) in Gulf Port, Mississippi; 8.3 mb in Pensacola, Florida; and 11.2 mb in Key West, Florida (NOAA, 1961-1986).

The tides in the Gulf of Mexico are less developed and have smaller ranges than those in other coastal areas of the United States. The range of tides is 0.3 meters to 1.2 meters, depending on the location and time of year. The Gulf has three types of tides, which vary throughout the area: diurnal, semidiurnal, and mixed (both diurnal and semidiurnal). Wind and barometric conditions will influence the daily fluctuations in sea level. Onshore winds and low barometric readings, or offshore winds and high barometric readings, cause the daily water levels either to be higher or lower than predicted. In shelf areas, meteorological conditions occasionally mask local tide-induced circulation. Tropical storms in summer and early fall may affect the area with high winds (18+ meters per second), high waves (7+ meters), and storm surge (3 to 7.5 meters). Winter storm systems also may cause moderately high winds, waves, and storm conditions that mask local tides.

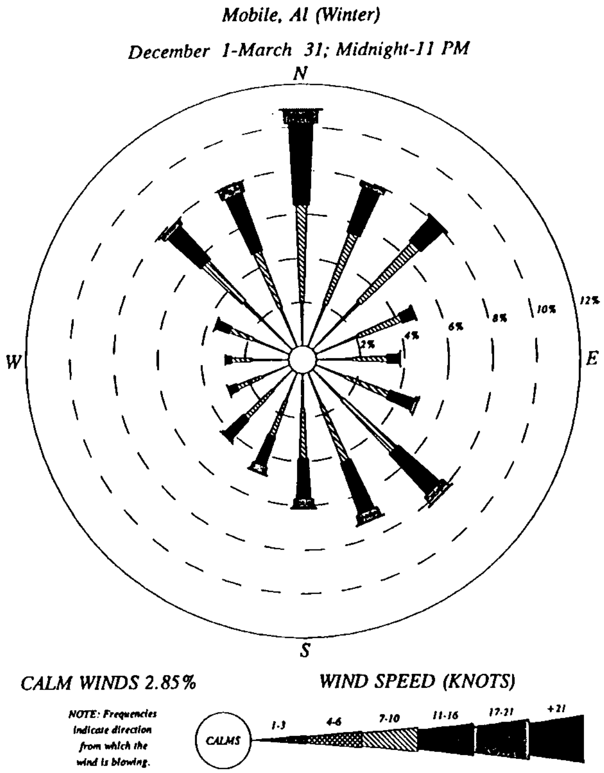
2.1.2 Temperature

In the Gulf, sea-surface temperatures range from nearly isothermal (29-30^{0}C) in August to a sharp horizontal gradient in January, ranging from 25^{0}C in the Loop core to values of 14-15^{0}C along the shallow northern coastal estuaries. A 7^{0}C sea-surface temperature gradient occurs in winter from north to south across the Gulf. During summer, sea-surface temperatures span a much narrower range. The range of sea-surface temperatures in the eastern Gulf tends to be greater than the range in the western Gulf, illustrating the contribution of the Loop Current.

Eastern Gulf surface temperature variation is affected by season, latitude, water depth, and distance offshore. During the summer, surface temperatures are uniformly 26.6^{0}C or higher. The mean March isotherm varies from approximately 17.8^{0}C in the northern regions to 22.2^{0}C in the south (Smith, 1976). Surface temperatures range as low as 10^{0}C in the Louisiana-Mississippi shelf regions during times of significant snow melt in the upper Mississippi valley (MMS, 1990).

The depth of the thermocline, defined as the depth at which the temperature gradient is a maximum, is important because it demarcates the bottom of the mixed layer and acts as a barrier to the vertical transfer of materials and momentum. The thermocline depth is approximately 30-61 m in the eastern Gulf during January (MMS, 1990). In May, the thermocline depth is about 46 m throughout the entire Gulf (MMS, 1990).

At a depth of 1,000 m, the temperature remains close to 5^{0}C year-round (MMS, 1990). In winter, nearshore bottom temperatures in the northern Gulf of Mexico are 3-10^{0}C cooler than those temperatures offshore. A permanent seasonal thermocline occurs in deeper offshelf water



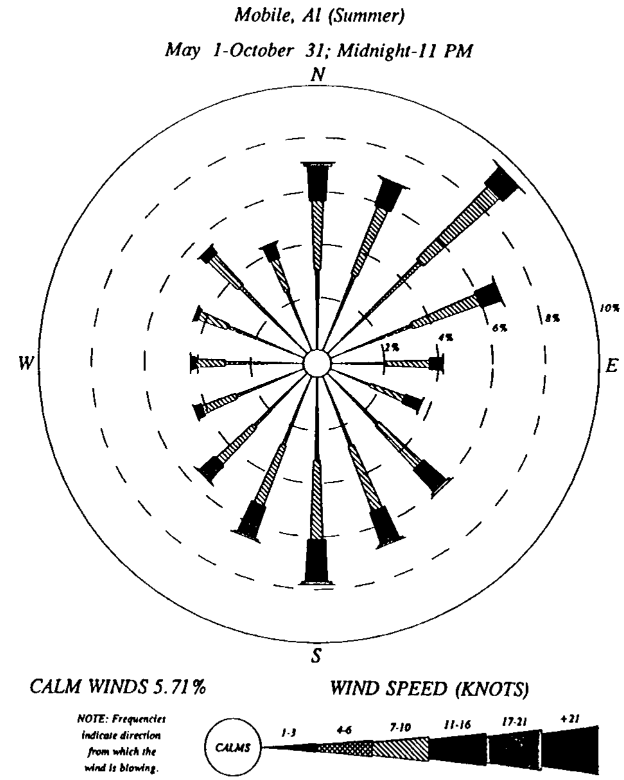


Figure 2-5. Winter (December - March) and summer (May - October) wind roses for the National Weather Service station at Mobile Alabama for the period 1984 - 1992 (Modified from SAIC 1997).

throughout the Gulf. In summer, warming surface waters help raise bottom temperatures in all shelf areas, producing a decreasing distribution of bottom temperatures from about 28EC at the coast to about 18-20^{0}C at the shelf break.

2.1.3 Salinity

Characteristic salinity in the open Gulf is generally between 36.4 and 36.5 parts per thousand (ppt). Coastal salinity ranges are variable due to freshwater input, draught, etc. (MMS, 1990). During months of low freshwater input, deep Gulf water penetrates into the shelf and salinities near the coastline range from 29-32 ppt. High freshwater input conditions (spring-summer months) are characterized by strong horizontal gradients and inner shelf salinity values of less than 20l ppt (MMS, 1990).

2.1.4 Density Profile

Data for water offshore Alabama were obtained from Temple et al. (1977). The data for the 7 meter and 14 meter contours are provided in Table 1.

Sigma-t/m (the density gradient per meter) calculated for the 0-3 meter interval of the 7 meter depth averages 0.692 kg/m^3 (n=6). For the 0-11 meter interval of the 14 meter depth, the average sigma-t/m is 0.163 kg/m^3 (n=5).

2.2 Chemical Oceanography

The Gulf of Mexico is a semi-enclosed system with oceanic input through the Yucatan Channel and principal outflow through the Straits of Florida. Runoff from approximately two-thirds of the U.S. and more than one-half of Mexico empties into the Gulf (MMS, 1990).

Of the 92 naturally occurring elements, nearly 80 have been detected in seawater (Kennish, 1989). The dissolved material in seawater consists mainly of eleven elements. These are, in decreasing order, chlorine, sodium, magnesium, calcium, potassium, silicon, zinc, copper, iron, manganese, and cobalt (Smith, 1981). In addition to dissolved materials, trace metals, nutrient elements, and dissolved atmospheric gases comprise the chemical make-up of seawater.

Table 2-1. Temperature and Salinity Data for Offshore Alabama

Day	Month	Temperature (EC)				Salinity (‰)			Density (kg/m^3)			Sigma-t		
		0 m	3 m	11 m	Bottom	0 m	3 m	11 m	0 m	3 m	11 m	0 m	3 m	11 m
Transect 1 E-37 (Alabama)														
26	2	13.8	13.8		13.8	35.5	35.5		1.027	1.027		26.60	26.55	
26	4	22.4	22.6		18.3	28.4	31.0		1.019	1.021		19.10	21.03	
19	6	25.6	25.5		20.6	30.5	32.3		1.020	1.021		19.79	21.22	
21	8	28.6	28.6		27.2	23.4	32.9		1.014	1.021		13.57	20.60	
25	10	24.1	24.3		24.4	30.8	33.3		1.020	1.022		20.45	22.33	
14	12	14.9	14.9		15.5	33.5	33.7		1.025	1.025		24.88	25.01	
Transect 1 E-38 (Alabama)														
26	2	12.9	12.9	12.9	12.9	35.2	0.0	35.1	1.027		1.027	26.58		26.51
25	4	23.0	22.4	17.8	17.8	30.5	31.1	35.1	1.021	1.021	1.025	20.54	21.16	25.43
19	6	25.1	24.9	21.7	21.7	32.7	32.8	35.9	1.022	1.022	1.025	21.60	21.69	25.03
21	8	0.0	0.0	0	0.0	27.4	33.3	35.3						
25	10	24.4	24.3	24.2	24.2	34.0	33.7	34.6	1.023	1.023	1.023	22.83	22.58	23.34
14	12	15.2	15.2	15.4	15.9	34.1	34.1	34.5	1.025	1.025	1.025	25.24	25.26	25.47

Source: Temple et al., 1977.

2.2.1 Trace Metals

Trace metals commonly found in seawater include antimony, arsenic, cadmium, lead, mercury, nickel, and silver. The average seawater concentrations of these metals and other metals characteristically found in drilling and production discharges from oil and gas facilities are presented in Table 2.

Table 2-2. Average Trace Metal Concentrations in Seawater

Constituent	Concentration Range (ug/l)
Aluminum	0 - 7
Antimony	0.18 - 1.1
Arsenic	2 - 35
Barium	5 - 93
Cadmium	0.02 - 0.25
Chromium	0.04 - 0.43
Copper	0.2 - 27
Iron	0 - 62
Lead	0.02 - 0.4
Manganese	0.2 - 8.6
Mercury	0.03[a]
Nickel	0.13 - 43
Radium	$5 - 15 \times 10^{-8}$
Selenium	0.052 - 0.50
Silver	0.055 - 1.5
Thallium	< 0.01[a]
Vanadium	2.0 - 3.0
Zinc	1 - 48.4

[a] The value is an average as reported in the source table.

Source: Adapted from Kennish, 1989.

2.2.2 Micronutrients

In Gulf of Mexico waters, generalizations can be drawn for three principal micronutrients--phosphate, nitrate, and silicate. Phytoplankton consume phosphorus and nitrogen in an approximate ratio of 1:16 for growth. The following nutrient levels and distribution values were obtained from MMS (1990): phosphates range from 0 ppm to 0.25 ppm, averaging 0.021 ppm in the mixed layer, and with shelf values similar to open Gulf values; nitrates range from 0.0031 ppm to 0.14 ppm, averaging 0.014 ppm; silicates range predominantly from 0.048 ppm to 1.9 ppm, with open Gulf values tending to be lower than shelf values.

In the eastern Gulf, inner shelf waters tend to remain nutrient deficient, except in the immediate vicinity of estuaries. On occasions when the loop current occurs over the Florida slope, nutrient-rich waters are upwelled from deeper zones (MMS, 1990).

2.2.3 Dissolved Gases

Dissolved gases found in seawater include oxygen, nitrogen, and carbon dioxide. Oxygen is often used as an indicator of water quality of the marine environment and serves as a tracer of the motion of deep water masses of the oceans. Dissolved oxygen values in the mixed layer of the Gulf average 4.6 mg/l, with some seasonal variation, particularly during the summer months when a slight lowering can be observed. Oxygen values generally decrease with depth to about 3.5 mg/l through the mixed layer (MMS, 1990). In some offshore areas in the northern Gulf of Mexico, hypoxic (<2.0 mg/l) and occasionally anoxic (<0.1 mg/l) bottom water conditions are widespread and seasonally regular (Rabalais, 1986). These conditions have been documented since 1972 and have been observed mostly from June to September on the inner continental shelf at a depth of 5 to 50 meters (Renauld, 1985; Rabalais et al., 1985).